Real World Rugged: Magnetic Versus Optical Rotary Encoders

A Discussion of Encoder Faults and Protection Methods

Electronic controllers that incorporate rotary encoders for position and speed sensing have been employed by a wide variety of industries around the globe, including food processing, printing, oil services, automotive manufacturing and factory automation. Machine control depends on sensors to translate real world information into computer language; however, sensors can deteriorate in harsh environments, decreasing their accuracy over time, or worse, causing them to fail entirely.

As clients demand a higher level of control integration from suppliers, how can design teams and engineering leaders reassure their customers they are building a measurement system versatile enough to perform in any environment? This white paper will review the shafted rotary encoder and its disadvantages, as well as discuss certain solutions which have led to the creation of a "real world rugged" sensor that is capable of surviving in any environment.

The Rotary Encoder | A Brief Introduction

Encoders are designed to output signals to an external machine controller, which as its name suggests, controls the machine it is monitoring. The signals sent from the encoder are interpreted by the controller, which adjusts the machine according to its programmed instructions.

Imagine a conveyor on a printing line. The conveyor is running boxes through a printing head that labels each box as it passes. In this application, the rate of the conveyor varies depending on the weight of the box, so it is important for the printing head to adjust its flow of ink accordingly to match the speed of the box as it passes. On the conveyor, an encoder can be used with a controller to find the speed of a moving box and correct the flow rate of printer ink to ensure the label is printed properly.

Figure A: Optical Encoder Exploded View

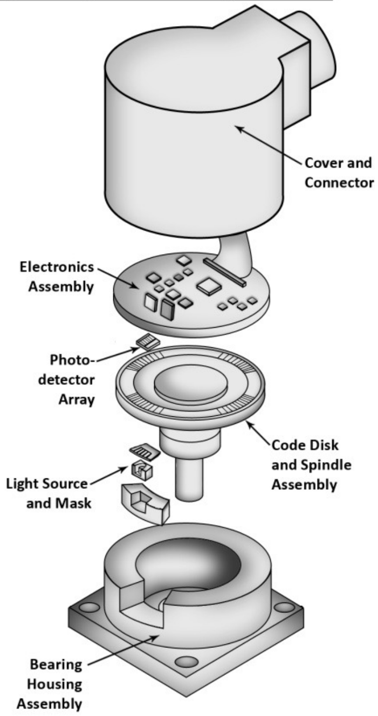
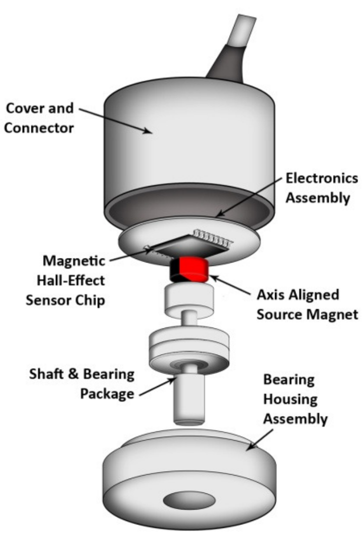


Figure B: Magnetic Encoder Exploded View



Sensing Techniques | Optical and Magnetic

There are two main sensing technologies in the encoder market, magnetic and optical. Optical encoders use the interruption of light to detect function. A rotating disc inside the encoder contains opaque lines or patterns, and as the disc is rotated through a light source, the patterns on the disc interrupt the projected light beam *(Figure A).* An internal photo-detector senses the pulsing light, which is translated and forwarded to an external control system via the encoder's electronics.

Unlike optical encoders, magnetic encoders find rotation by sensing change in a local magnetic field. The typical magnetic rotary encoder relies on a silicon chip which contains a hall-effect sensor. The hall-effect sensor, which is mounted within close proximity to a rotating magnet, finds the relative strength of the magnet's corresponding magnetic field and outputs a voltage relative to the change in magnetic polarity *(Figure B).* The varying voltage is translated by the encoder's electronics and sent out to an external control system.

In the early stages of magnetic encoding, the technology was limited and only appropriate for applications that did not require a high-precision sensor. Therefore, optical encoders were the first used in most machine control systems, and as a result, the optical encoder has been, for years, the assumed standard for precise rotary motion detection.

Encoder Design | Building Reliability

The basic blueprint for the rotary encoder has been somewhat the same since its widespread acceptance into the industrial world. From the early stages of development both magnetic and optical encoders have relied upon the same structural components for function, which consist of an electronic package specific to the encoder's type, magnetic or optical, an outer casing to protect the encoder's internal mechanics, ball bearings to contain the encoder shaft, and the encoder's shaft. Packaged in different housings, rotary encoders come in many variations, but what makes encoders lasting and flexible is how well their four basic components have been designed.

Encoder Electronics | Brain Versus Brawn

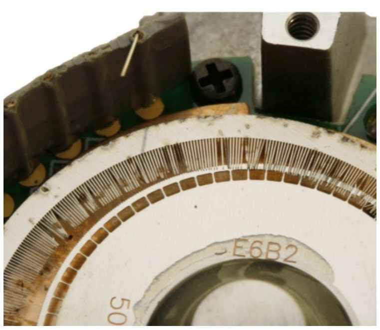
The sensing technology of optical encoders is prone to self deterioration

Both optic and magnetic technologies boast their own unique strengths and weaknesses. In a simple comparison of sensing technologies, one might imagine optical encoders, which are the best choice for high-resolution measurement, as the brains among encoders and magnetic sensing technology as the brawn. If unsuited for the demands of the application, the chosen encoder's precision is liable to deteriorate over time until, because of wear, it fails entirely.

To claim perfect accuracy an encoder must return the same amount of pulses every time the sensor's shaft is moved an exact distance. If an encoder marks twenty pulses for every degree of shaft rotation then it must do so from the day it starts to the day it is relieved of operation. The optic lens and the internal rotating disk of optical encoders are considerably more prone to damage than the simple microchip design of magnetic encoders. Magnetic encoders, which use a Hall-effect microchip, contain almost no moving parts; however, in optical encoders the whole of their sensing is dependent upon their fragile mechanics.

Due to the nature of their sensitive components, optical encoders are liable to a type of "brain damage" not possible with their magnetic counterpart. For optic encoders their rotating disk within the sensor is paired with an optical eye mounted near, but not touching, the rotating disk. In instances of extreme vibration or unexpected jolts the encoder's disk is liable to flex, causing contact between the disk and the optical sensing element *(Figure C).*

Figure C:
Optical encoder with a failed code disk assembly



Above: A closer look reveals a destroyed coded disk, a result after a series of handicapping jolts

When an optical encoder's moving mechanics knock against themselves the resulting misalignment curtails performance standards. Eventually the misaligned mechanics translate into a complete failure of the coded disk as it is forced to rotate through or around its surrounding components.

While jolts from mechanical acceleration and deceleration, environmental vibration, and automated assembly processes can quickly damage an optical encoder, magnetic encoders because of their solid state design, are suited to handle any sort of external force without risking accuracy. The microchip technology now found in magnetic encoding is responsible for increased resolution capabilities and design flexibility, and has allowed for a sensor that is far more durable than its optical counterpart.

Encoder Seals | Environmental Uncertainty

Absorbed moisture is a slow but sure means to encoder failure

Brute forces are by no means the only threat to an encoder's longevity. Designed to seal out the encoder's surrounding environment, the encoder's shell protects its internal components. In industrial applications, where dust and moisture are unpredictable, a sensor's reliability can unsuspectingly turn for the worse. Knowing that an encoder's seal is only as good as its weakest point, how can design teams find assurance that their sensor will survive a given environment?

Traditionally, the rotary encoder contains a shaft seal, a seal between the casing and its bearing package, and sometimes a seal on its output connector. The seals, which are sensitive to temperature, are vulnerable even to the encoder's own latent heat, and thus, incapable of guaranteeing complete protection for any extended period of time.

Rubber seals do not prevent the exchange of water vapor

For a moment consider a rotary encoder tracking the rate of a conveyor in a chocolate crème donut plant. The encoder functions uninterrupted finding the rate of the conveyor and is turned off only at the end of the day for wash down. When the encoder is in operation, its components generate heat, which increases the pressure of the environment sealed within the encoder's body. The warm expanded air, pushed out from within the heated encoder, is later pulled back into the housing when it is powered down and allowed to cool.

Figure D: Absorbed Water Inside Encoder

The simple principle of equalizing air pressure translates into sensor failure as the encoder draws moisture in via the cooled air it pulls in everyday after shut down *(Figure D).* Risks of encoders malfunctioning because of bad seals are amplified when water, dust and chemicals are prevalent in the sensor's application. Employing an effective method to remove encoder seals would prevent a near certain loss of investment caused by sensor failure.

Optical encoders, as explained earlier, need space within the sensor to allow its mechanics to rotate freely, so by design, seals are an integral part of their hollow bodies. With magnetic encoders and their simplified electronics, however, it is possible to cover the electronics package with a protective substance like plastic without interrupting the encoder's functionality. Fully encapsulating the encoder's electronic package removes any potential contact between its moisture sensitive components and the application's environment.

Shaft & Bearings | Avoiding the Inevitable

Encoder bearings are deceptively incapable of handling any sort of pressure which result from shaft misalignment

For the rotary encoder to operate, its shaft must be mechanically coupled to its parent application. Providing the rotary encoder's shaft with the means to rotate freely, ball bearings are a key ingredient to the sensor's function. It is a common misconception, however, that because the encoder's bearings are internal, they are designed to carry significant loads, such as those resulting from installation misalignment.

Side loads resulting from misalignment are one of the primary mechanical failures for rotary encoders. Even if misaligned by 0.003 of an inch, the resulting side load can translate into several hundred pounds. Yet misalignment from improper installation is not the only threat to an encoder's bearings. Many technicians assume--if installed correctly--an encoder can be hard-mounted to its application, but what most don't understand is that over time even the slightest wear in the application's bearings can mean extreme stress for the encoder's bearing package.

Proper installation cannot guarantee protection from bearing failure

For example, consider a shaft that belongs to a simple electric motor. At the initial installation the encoder is mounted correctly in line with the application, but as the motor ages, so do the motor's bearings. Guided by the worn bearings the motor's shaft is allowed to wobble as it rotates. The application's wobbling shaft transfers negatively to the encoder's bearings as side load, inevitably leading to the failure of the encoder.

Eliminating bearing overload would substantially increase the reliability of rotary encoders, but without an effective means to prevent bearing wear, there will always be the potential for shaft wobble. To avoid bearing failure, some encoder manufacturers have done away with the encoder's shaft altogether, creating what is called a "non-contact" encoder. The non-contact encoder tracks the rate of the rotating application without physically coupling to the application's shaft.

Non-contact sensing is only available with magnetic technology. For optical encoders, their internal coded disk, which rotates when the encoder is in operation, depends on its shaft and bearing package. Non-contact magnetic encoders need only a magnet mounted within the proximity of the sensor to operate. With no mechanical coupling, the non-contact magnetic encoder avoids unpredictable mechanical wear, and eliminates the risk of failing bearings by removing the need for bearings entirely.

Quality Encoders | Choosing Your Manufacturer

Heavy duty and rugged are attractive but empty descriptors used by encoder manufacturers

Choosing an appropriate encoder can be a headache, especially when the design calls for the encoder to be built into the system. As discussed above, poorly suited encoders are likely to fail due to their inability to cope with their operating conditions, and as a result, the service required for replacement can mean wasted revenue and lost production. If utilized correctly, however, a well-suited rotary encoder can operate hiccup-free for years of productive service.

Heavy duty and rugged are terms regularly used to describe encoders; the difficulty in choosing a well-designed encoder is that these terms are not held to any sort of measurable standard. Encoders described as heavy duty, extremely rugged, and reliable are often designed with the same faults this paper has shown lead to failures. To ensure that the encoder chosen for the job is "real world rugged" look to see the sensor has been constructed with the following protection methods:

- **Solid state microchip design:** To guarantee protection from vibration and axial jolting the encoder should not depend upon fragile mechanics for function. Only magnetic encoders, which use a solid silicon microchip for sensing, provide a natural resistance to forces that regularly destroy optical encoders.

- **Moisture Resistance:** Absorbed moisture can easily lead to encoder failure when rubber o-rings are the only means sealing the encoder's housing. An encoder claiming true moisture resistance must have zero potential for water absorption. One technique, developed by magnetic encoder manufacturer Joral, is to encapsulate the encoder's electronic package with a plastic epoxy, creating an impenetrable barrier between the sensor's electronics and its environment.

- **Alignment Forgiveness:** Shafted encoders will not tolerate shaft misalignment. A flexible coupling may be employed to help with shafted encoder alignment problems. Non-contact rotary encoders avoid the potential for bearing failure by sensing rotation without the need for a shaft and bearing package, as well as remove the physical limitations which prevent shafted encoders from mounting upside down and in hard to access places.

Joral Encoders | Patented Non-Contact Design

Joral LLC is a company devoted to solving problems, and their design team is responsible for techniques that have greatly enhanced the performance of magnetic encoders. Initially proven in the logging industry, the protection methods adopted by Joral redefined what logging operators considered to be a durable encoder. With a fully encapsulated electronic package and high resistance to extreme vibration, Joral's shafted encoders took the first step toward developing a stronger rotary encoder *(Figure E)*.

Figure E:
A cutout of the Joral shafted magnetic encoder

Though more lasting than the competition, Joral's shafted encoder suffered from the same drawback as all shafted encoders; the need for a mechanically coupled shaft meant potential bearing failure and restricted design flexibility. Seeking to develop an encoder versatile enough for any industry, Joral returned to the drawing board and invented their line of non-contact magnetic encoders.

Figure F: The Joral non-contact encoder

The Joral non-contact magnetic encoder boasts capabilities of sensing rotation up to one half-inch from the paired application magnet. Joral's patented technique of non-contact sensing is possible because of a magnetic coupling created between a magnet built into the face of the non-contact encoder and a magnet installed on the parent application *(Figure F)*. When the non-contact encoder is placed within close proximity of the magnet installed on the application; the magnet, designed into the encoder, spins via the attraction between the two opposing magnetic fields.

Joral's non-contact encoder design does more than just remove the need for bearings and mechanical alignment. The face of the non-contact encoder, which normally contains the encoder's shaft, is completely sealed. The sealed face of the encoder combined with a totally encapsulated electronic package make for a sensor which is IP69K and can operate submerged in water. Revered as the most unique encoder solution to hit the market since the sensor's first development, Joral's non-contact design is the only of its kind.

The Final Word | From Development to Production

Figure G: Non-Contact Encoders
30mm (above) & 18m (below)

Incorporating encoders into machine control can be a breeze so long as the sensor is fit for its duty. More robust than optical encoders, magnetic encoders are on the leading edge of encoder technology, and they are still today redefining what designers consider possible from rotary encoders. By observing the problems of standard rotary encoders, one can gather an understanding of what to look for in an encoder which claims to be harsh duty.

Joral developed their magnetic encoders understanding the same encoder vulnerabilities this paper established handicap most sensors of its kind. Joral non-contact encoders eliminate the possibility of bearing failure and boast that elusive "real world rugged" quality. Offered in a variety of electronic interfaces, Joral's non-contact encoders are available in multiple housing sizes including 18mm, 30mm, and 58mm *(figure G)*. To help with integrating their encoders into design Joral offers a non-contact designer kit that includes a sample encoder as well as a variety of application magnets.

Jordan Schrubbe, June 25, 2010